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THESIS

ENSURING RESILIENCY OF THE MILK AND DAIRY INDUSTRY IN CALIFORNIA

by

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13. ABSTRACT (maximum 200 words)

We model the milk and dairy industry in California focusing on the production, processing, and distribution of bulk milk at the county level. We analyze the sensitivity of this industry when faced with worst-case disruption, where a "worst-case" disruption corresponds to the greatest shortage of milk supply throughout California. The major highways in California are used to connect all of the counties and illustrate where the bulk milk is moving. We utilize Attacker-Defender (AD) modeling techniques to determine where worst-case disruptions occur. This reveals vulnerabilities within the milk and dairy industry. We examine three specific scenarios: (1) a quarantine of each county due to a Foot and Mouth Disease (FMD) outbreak or any other event that would cause the complete stoppage of production, processing, and movement of milk in a county over a seven day period, (2) 1 to 15 attacks on the milk and dairy industry in a 45 day time period, and (3) the isolation of Northern and Southern California over a seven day time period that could be caused by a natural disaster.

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ENSURING RESILIENCY OF THE MILK AND DAIRY INDUSTRY IN CALIFORNIA

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ABSTRACT

We model the milk and dairy industry in California focusing on the production, processing, and distribution of bulk milk at the county level. We analyze the sensitivity of this industry when faced with worst-case disruptions, where a "worst-case" disruption corresponds to the greatest shortage of milk supply throughout California. The major highways in California are used to connect all of the counties and illustrate where the bulk milk is moving. We utilize Attacker-Defender (AD) modeling techniques to determine where worst-case disruptions occur. This reveals vulnerabilities within the milk and dairy industry. We examine three specific scenarios: (1) a quarantine of each county due to a Foot and Mouth Disease (FMD) outbreak or any other event that would cause the complete stoppage of production, processing and movement of milk in a county over a seven day period; (2) 1 to 15 attacks on the milk and dairy industry in a 45 day time period; and (3) the isolation of Northern and Southern California over a seven day time period that could be caused by a natural disaster.

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LIST OF ACRONYMS AND ABBREVIATIONS

AD	Attacker-Defender
CalEMA	California Emergency Management Agency
CARVER-Shock	Criticality Accessibility Recuperability Vulnerability Effect, Recognizability
CDFA	California Department of Food and Agriculture
DHS	Department of Homeland Security
FASCAT	Food Agriculture Sector Criticality Assessment Tool
FMD	Foot and Mouth Disease
MDFS	Milk and Dairy Food Safety Branch
NAADSM	North American Agriculture Disease Spread Model
USDA	United States Department of Agriculture
US FDA	United States Food and Drug Administration

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EXECUTIVE SUMMARY

This thesis analyzes the milk and dairy industry in California focusing on the production, processing, and distribution of bulk milk at the county level. The model we use examines the sensitivity of this industry when faced with worst-case disruptions. We utilize Attacker Defender (AD) modeling techniques to determine where worst-case disruptions occur. This informs us where vulnerabilities exist within the milk and dairy industry. We examine three specific scenarios: (1) a quarantine of each county due to a Foot and Mouth Disease (FMD) outbreak or any other event that would cause the complete stoppage of production, processing and movement of milk in a county over a seven day period; (2) 1 to 15 attacks on the milk and dairy industry in a 45 day time period; and (3) the isolation of Northern and Southern California over a seven day time period that could be cause by a natural disaster.

In our model, we create a network that approximates the flow of milk starting at the dairy farms where milk production occurs, moving to processing facilities, and eventually getting to the consumers in California. We use an abstraction from the Food Agriculture Sector Criticality Assessment Tool (FASCAT) as our basis for the milk and dairy industry, and we incorporate major highways into the network to connect all of the counties in California. We also take into account the rapid movement of milk by introducing a time component to the model. The resulting model enables us to estimate where the worst-case disruptions occur and analyze the impact of varying disruption scenarios.

Our model produces key insights into the milk and dairy industry. We learn that the overall milk and dairy industry is able to be very responsive to worst-case disruptions, and that five simultaneous attacks are necessary to cause shortages to California consumers. We also learn that separating Northern and Southern California, as may be caused temporarily by large-scale flooding can have drastic consequences to the supply of bulk milk, causing shortages in Southern California.

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I.   INTRODUCTION

The Department of Homeland Security (DHS) has identified agriculture as a critical infrastructure for the United States. The agriculture industry is vulnerable to both intentional and unintentional disruptions. One large concern is an intentional disruption caused by agro-terrorism. "Agro-terrorism is a subset of bioterrorism, and is defined as the deliberate introduction of an animal or plant disease with the goal of generating fear, causing economic losses, and/or undermining social stability" (Monke, 2007). The agriculture industry is also vulnerable to an unintentional disruption such as an outbreak of foot and mouth disease (FMD) (Hagerman, McCarl, Carpenter, & O'Brien 2009). These disruptions have the potential for loss of life, as well as widespread economic and social ramifications (DHS, 2007).

The State of California and the nation as a whole would be greatly affected by a disruption to the milk and dairy industry in California. California is the largest producer of agriculture products in the United States. The California agriculture industry generates 36 billion dollars in sales annually. California's milk and dairy production accounted for 5.9 billion dollars in sales in 2009, making California the nation's leading dairy producer (CDFA, 2010a). During that year, California's milk and dairy industry produced 21% of the nation's milk supply with 40.4 billion pounds of bulk milk. The number of people employed by the dairy industry in California is 400,000. California's milk and dairy products are not only used locally, but they are shipped throughout the United States as well as exported overseas.

The milk and dairy supply chain is comprised of dairy farms, processing facilities, wholesale distribution centers, and retailers. The supply chain begins when dairy farms produce raw milk. The raw milk is supplied to creameries that process the raw milk into consumable milk or other dairy products. Once processing is complete, milk is shipped out for further processing before going to wholesale distributors. From the wholesale distributors, the milk goes to the retailers where it is purchased by consumers. This is a general flow of the farm-to-table continuum for milk.

Two state agencies that are particularly concerned about the well-being of the milk and dairy industry in California are the California Department of Food and Agriculture (CDFA) and the California Emergency Management Agency (CalEMA). CDFA oversees the regulations that directly affect the milk and dairy industry through their Milk and Dairy Food Safety Branch (MDFS). MDFS ensures the quality and safety of the dairy industry by inspecting dairy farms and milk processing plants, collecting samples of bulk milk to assure consumer safety, ensuring that tests used to determine payment are accurate, and evaluating the dairy farms, milk plants, and laboratories for the United States Food and Drug Administration (US FDA) (CDFA, 2011). CalEMA is in charge of the coordination and response to major disasters in support of local governments. They are also responsible for the states readiness to respond and recover from all hazards to include natural, manmade, war caused emergencies, and disasters (CalEMA, 2011). CalEMA works closely with DHS on their efforts for security to critical infrastructures at the state level. These two state agencies work together in examining possible vulnerabilities to the milk and dairy industry.

There are multiple concerns about the vulnerabilities of the milk and dairy industry. One such concern is an interruption to the supply chain resulting in shortages for consumers. This scenario would impact not only infants and elderly consumers, but also the producers, processors, and shippers within the milk and dairy industry in California. Depending on the duration and severity of the interruption to the milk supply, market share may be lost to out-of-state dairy producers. A second concern is an interruption in processing to the milk and dairy supply chain where raw milk cannot be processed and requires disposal. This is a concern due to the fact that raw milk has the potential to be an environmental hazard if disposed of improperly. A final concern is either a deliberate or non-deliberate contamination of the milk supply. This is a concern because a contamination can quickly spread to consumers through the existing distribution channels of the milk and dairy industry. The consequences in this scenario are also severe due to the high velocity of the milk supply chain and the number of people who could consume the contaminated milk.

This thesis focuses on assessing the impact of disruptions or delays to the milk and dairy industry. We develop a network flow model of the normal daily operations of bulk milk movement in California. The network is made up of milk production, processing and consumption in each California county, and it also includes the major roadways connecting counties. This model of daily operations gives us an appreciation of the speed and complexity of the milk and dairy industry. We use the model to identify the locations of worst-case disruptions. We define a worst-case disruption to mean a disruption that causes the greatest amount of shortage in milk supply throughout the state of California. Collectively, these scenarios help us to assess the responsiveness of the milk and dairy industry when disruptions occur. We do not analyze the impact of contamination to the milk and dairy supply or the effects of disposal of large amount of bulk milk.

Using this model, we investigate the impact of three disruption scenarios and perform analysis to determine which entities are critical within the milk and dairy industry in California. The first scenario that we examine is a FMD outbreak in a single county. By considering each county in turn, we identify the critical counties in the milk and dairy industry. In the second scenario, we examine where worst-case disruptions occur to the milk production processing, and distribution in each county. We determine the severity of the disruption by computing the demand for milk that is not met by California's milk and dairy industry. Finally, we analyze an isolation of one part of California from another, for example due to flooding.

The rest of the thesis reviews previous work within this subject, documents the methodology that we use to obtain our results, analyzes several case studies, and reports our conclusions.

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II. LITERATURE REVIEW

We briefly review three main topic areas in the academic literature that give context to this thesis. The first area of research is modeling the effects of deliberate contamination to the milk and dairy industry, and effects of foreign animal disease outbreaks. The second area of related research is the Attacker-Defender (AD) style of models developed at Naval Postgraduate School. Finally, we review the tools currently used for analysis by CDFA and CalEMA, because these tools serve as a starting point for our network flow model.

A. MILK AND DAIRY INDUSTRY

Liu and Wein (2005) analyze the effect of a deliberate contamination to the milk and dairy industry in California using a hypothetical scenario in which, a terrorist introduces a botulinum toxin. They argue that a relatively small amount of the contaminant introduced in either the holding tank at the dairy farm, the truck transporting milk, or the bulk milk holding silos at the processing plants could lead to consumer casualties. Their model estimates that 568,000 people would get sick from poisoning on the introduction of one gram of botulinum toxin. Their article demonstrates the potential effect of one vulnerability within the milk and dairy industry and its impact on a large portion of the population. Due to this and other possible potential vulnerabilities, analysis within the milk and dairy industry is important.

Hagerman et al. (2009) document the economic impact of a FMD outbreak to the milk and dairy industry in California. Their research provides a quantitative approach to assist decision makers on the impact of differing strategies for prevention, intervention, and recovery. In their analysis, they simulate three different scenarios, one with no vaccination during a FMD outbreak, one with a 10 Km ring of vaccinated dairy cows, and the last scenario is with a 20 Km ring of vaccinated dairy cows. They adjusted five parameters that deal with the length of time to detect a FMD disease outbreak of 7 days, 10 days, 14 days, 21 days, and 22 days. Their analysis suggests that a best case scenario, in which, officials use a 10 Km ring of vaccinating dairy cows and determine an outbreak

after just seven days, they estimate a direct economic loss of 3,956.72±695.4 (2004$M). In the worst case scenario, corresponding to the use of 20 Km vaccination ring and not finding the outbreak until day 22, they estimate a direct economic loss of 71,682.91±6906.07 (2004$M). The size of this potential economic impact on California demonstrates the need for additional analysis on impacts to the milk and dairy industry from a FMD outbreak. We specifically model a scenario concerning a FMD outbreak at the level of a single county in California.

B.   ATTACKER DEFENDER MODELING

Our model formulation and analysis of the milk and dairy industry follows the attacker-defender (AD) models presented in Brown et al. (2005, 2006). These articles introduce the idea of AD bi-level optimization models to determine where the worst case attacks by an intelligent adversary could occur in a system. The starting point is a "defender" or "operator" model that prescribes the activities that yield the best possible system performance (e.g., minimize lost or maximize throughput). The "attacker" is a hypothetical adversary who wants to disrupt system performance (e.g., maximize cost or minimize throughput). The AD model finds the attacks that result in worst-case system performance, even after the defender had responded in the best possible manner. We apply the AD modeling techniques in our analysis of the milk and dairy industry.

C.   CURRENT TOOLS

There are several tools used by CDFA and CalEMA to assess vulnerabilities to the milk and dairy industry in California. The tools that the state agencies are currently using are the Food Agriculture Sector Criticality Assessment Tool (FASCAT), Criticality Accessibility Recuperability Vulnerability Effect Recognizability (CARVER-Shock), and the North American Agriculture Disease Spread Model (NAADSM). All of these tools were developed at the federal level by United States Department of Agriculture (USDA) and DHS.

FASCAT is a data collection tool used by state agriculture and emergency management agencies. Either USDA or DHS solicits a "data call" for information on the

impact of certain predetermined scenarios from their state agency partners (CDFA and CalEMA). FASCAT helps to collect responses from each of the states. The responses are collected, and the scenarios are ranked based on severity of impact. This ranked list is used to determine where limited funding can go to make the different sectors in the food and agriculture industry more resilient (FASCAT version 1.2, 2009). The drawback from using FASCAT is that it does not take into account real operational data, such as production quantities for dairy farms in a state, to determine the impact of differing worst case scenarios. The next version of FASCAT called FASTRANS promises to analyze the effects of transportation issues on differing agriculture commodities (Beckham, Hoffman, and Orosz, 2011).

CARVER-Shock differs from FASCAT in that it attempts to identify vulnerabilities by having each user answer multiple questions about their farm, ranch, or area of responsibility. Carver-Shock is designed to be used by multiple levels within the agriculture industry. This includes people working for state agriculture agencies all the way down to the individual farm or ranch owners. Once all of the questions are answered, the user receives a report on the vulnerabilities for their area of responsibility. This tool helps farmers determine where vulnerabilities exist (FDA, 2010).

NAADSM is a tool that uses a stochastic simulation to estimate the spread of a foreign animal disease outbreak (Hill & Reeves, 2006). The second most important scenario that concerns CDFA is an outbreak of foot and mouth disease (CDFA 2010c). While we are also concerned about the effects to the milk and dairy industry of a foot and mouth disease outbreak, the NAADSM tool was not used in this research.

D.   OUR CONTRIBUTION IN CONTEXT

The basic model in this thesis can be used for additional analysis on vulnerabilities of other agriculture commodities. Chapter 3 details our approach to tying the process flow of the milk and dairy industry with a transportation network. Additionally it shows how we collected the data for use in our model, as well as the mathematical formulation we use to determine where worst case disruptions occur in different scenarios.

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III. MODEL FORMULATION

We build our model in three steps. In the first step, we develop a network from an abstraction of the milk and dairy process flow in FASCAT, and we overlay a transportation network consisting of major roadways that connect the counties in California. The second step is data collection and extrapolation for the amounts of bulk milk produced, processed, and distributed. The final step is the development of the mathematical program that we use to solve for the amount of shortages of bulk milk that results in each county for each of several given scenarios.

A. NETWORK MODEL

We begin by examining the process flow of the milk and dairy industry used in FASCAT. The milk and dairy industry is comprised of dairy farms, processing facilities, wholesale warehouses, and finally retail stores. A visual depiction of the flow of milk through the FASCAT model is shown in Figure 1. Milk processing occurs in two levels. The first level of processing takes bulk raw milk as an input and then outputs pasteurized milk and other dairy products. The second level of processing takes the output from the first level and processes it further for specific dairy products. FASCAT models this process flow by connecting inputs that are required for dairy farms, production from the dairy farm to the first processing level, output from the first processing level to the second processing level, distribution of the finished products to wholesale warehouses, retail stores, and finally then to the consumer. We use this process flow to get an understanding of the entities that are involved within the dairy industry. Our next step is determining how we are going to take this process flow and create a mathematical model for our analysis.

We take the information from FASCAT and create an abstraction to build our network of the milk and dairy industry. In our modeling, we focus on the production of bulk milk at the dairy farms and the processing of bulk milk at the first and second level creameries. We visually see this in the light gray highlighted nodes that are in Figure 2.

We also need to represent the physical movement of bulk milk between the dairy farms and milk processing centers.

Product Flow of Dairy
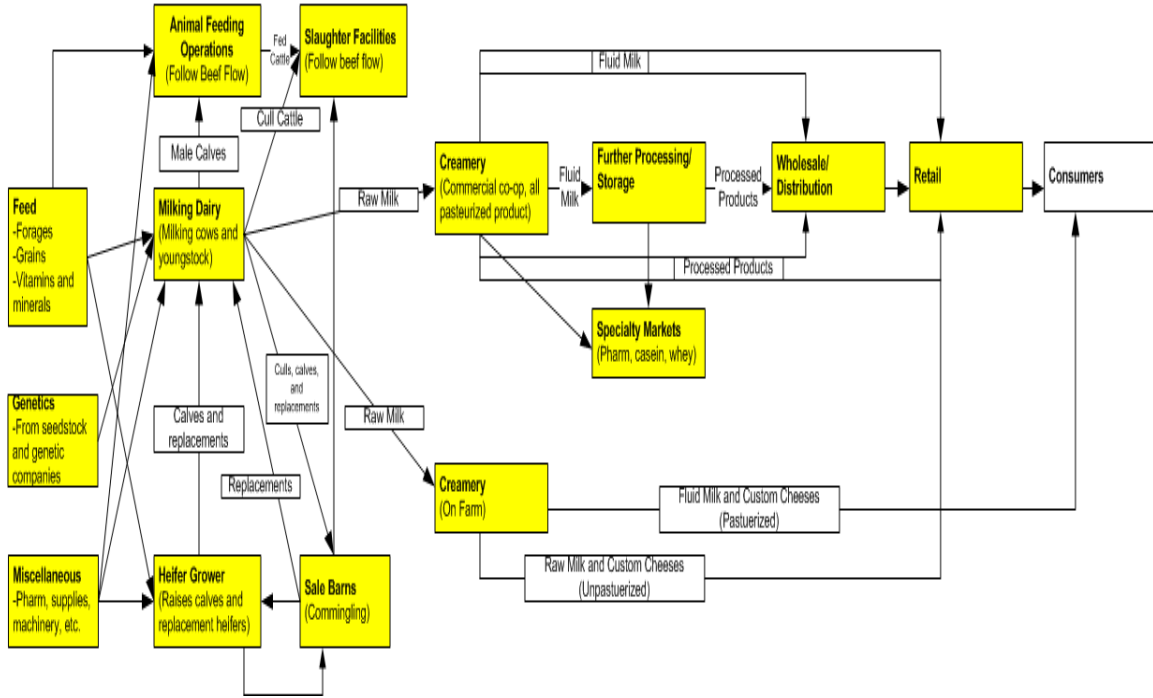
Figure 1.   Flow of milk through the milk and dairy process found in FASCAT. We use this process flow to form our abstraction of the FASCAT model, which, focuses on the dairy farms and the first and second processing levels (from NCFPD, 2011).

Figure 2 displays the abstraction of FASCAT that we create for each California County. We create a transportation network consistent with this FASCAT framework that enables the milk to move from the farms to the creameries within a county and between counties. This is shown by the medium gray highlighted nodes connecting the farms and the creameries in Figure 2. We also define "level 1" and "level 2" as the two stages that can be used in processing of bulk milk. "Level 1" takes as input the raw milk from the farms and "level 2" does additional processing for specific dairy products. We see this separation with the dotted lines in Figure 2. Finally, we show that the movement of milk

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ends with the population in the county, moves to another county, or goes out of state with the dark gray highlighted nodes in Figure 2.
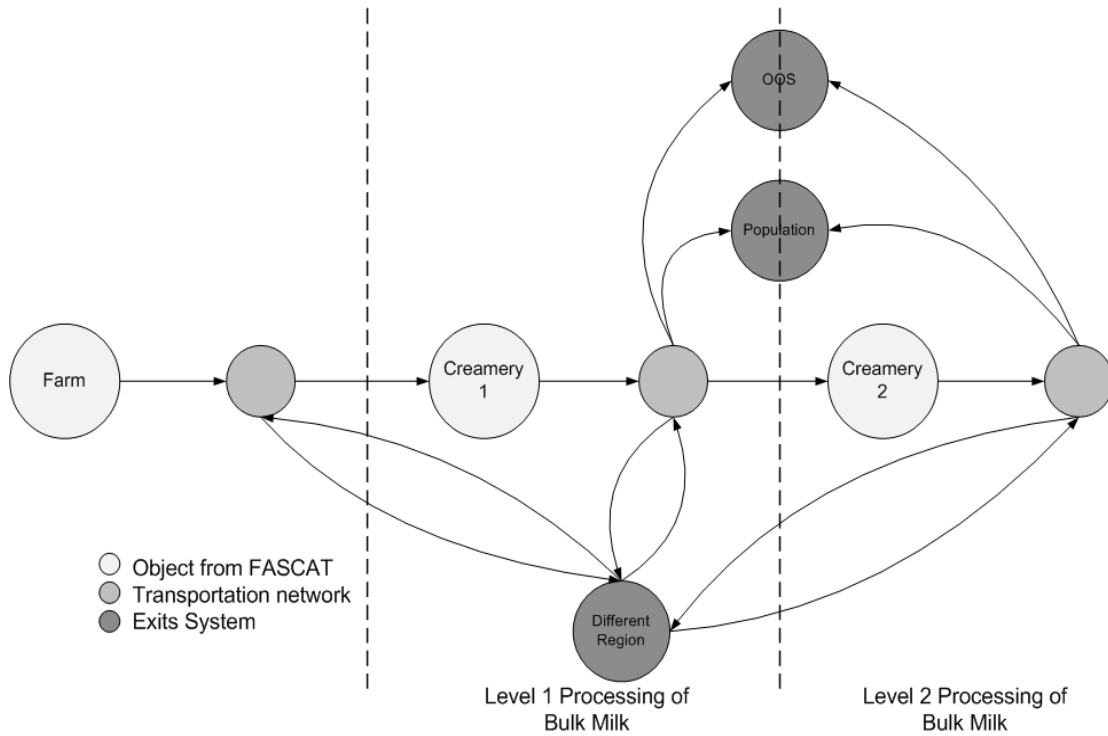
Figure 2.   Abstraction of the bulk milk process flow with a transportation network. Our abstraction focuses on the dairy farms, first level and second level processing facilities, and the transportation of bulk milk throughout California. This figure represents a single county. Light gray nodes represent an abstraction of FASCAT. Medium gray nodes represent transportation. Dark gray nodes represent exits from the county.

This abstraction of the flow of milk from FASCAT represents the production, processing and movement of milk within each county in California. Our next step is to take this abstraction and add a transportation network. This allows us to connect all of the counties where milk production, processing, and consumption occur. The transportation network that we are using is visually depicted in Figure 3. This network connects the major roadways through each of the counties. Each node in Figure 3 is, in fact, a set of nodes like those depicted in Figure 2.

Our final step in creating our milk and dairy network model is to introduce a time layering effect. This is essential to model since bulk milk moves extremely quickly from

production on the dairy farms through processing and finally to consumers. We take this effect into account by the milk and dairy industry with time periods. Each time period represents the movement from one day to the next. This is shown in Figure 4.
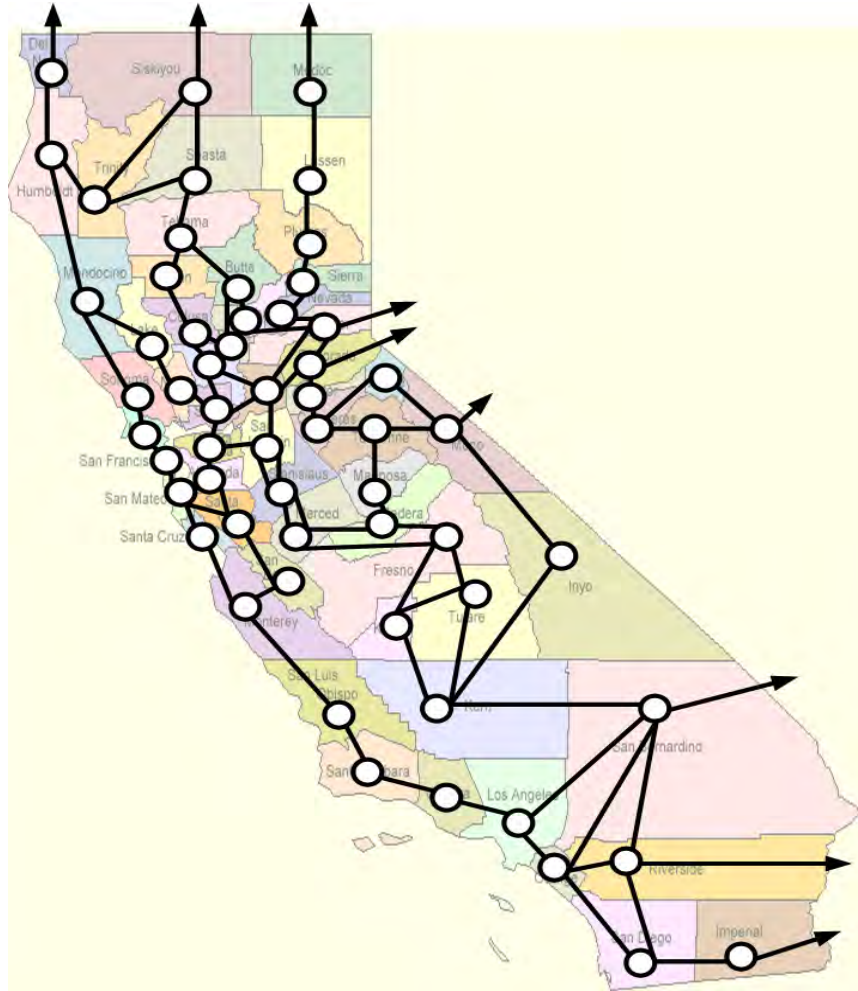
Figure 3.   Transportation network connecting all of the counties in California. Our network contains a single node for each county in California. The edges connecting counties were derived primarily from highways US-101, I-5, I-10, US-395, I-15, CA-99 Background image is from Digital-Topos-Maps.com. (Digital-Topos-Maps.com, 2011)

The following is one example of the movement of milk through our network to include our time layering. If raw milk is processed in the same county where it is produced, the shipment from farm to creamery happens within the same time period. The following processes consume about a day in reality, and so the edges representing them

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cross time layers: Shipping milk supplies between counties or processing milk either from raw to "level 1" or "level 1" to "level 2" each take one time layer. All other processes take considerably less time, and the edges representing them remain within the same layer.
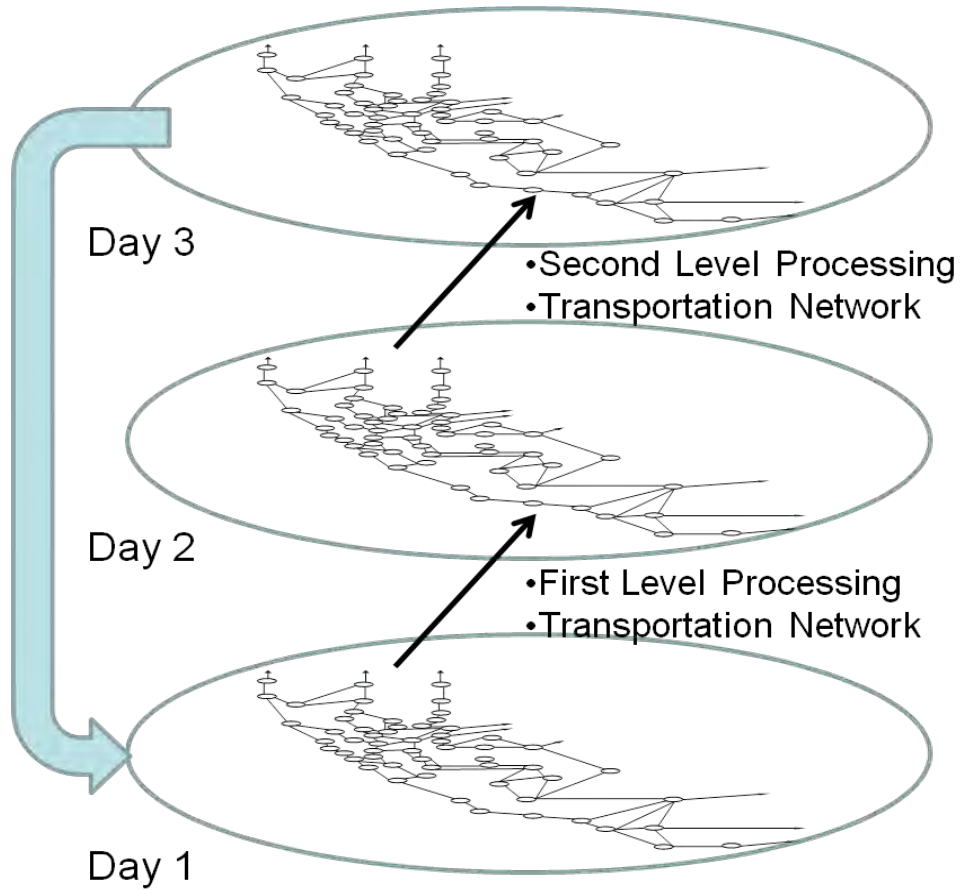
Figure 4.   Illustration of the movement of bulk milk through three different time layers or days. This illustration shows how milk changes time layers. The bullets indicate that milk can change time layers when going through the first or second level of processing and when milk enters the transportation network.

B.   FULL MODEL

Our abstraction from FASCAT depicts the flow of milk from production to consumption for a single county in California. To solve our network model of the milk and dairy industry in California, we must expand our model by splitting the nodes seen in

Figure 2, and account for the time layers. This new network model for a single county is shown in Figure 5.

We begin at the dairy farms and our first node, denoted *FarmStart,* which, connects to *FarmEnd* at time period *t*. Flow along the arc connecting these nodes accounts for the milk production on the dairy farms in the county. We set the lower and upper bound on this arc equal to the amount of raw milk each produced in this county. Because dairy farms must continuously produce milk, the lower bound cannot be zero. Also, the upper bound cannot exceed the capacity of raw milk that the milk producing cows can make in each county.

Between the dairy farms and creameries in this county, we have a transportation node called *Trans1*. We label this node with time period *t* because transportation of raw milk from the farms happens on the same day. The arc connecting *FarmEnd* to *Trans1* has an upper bound to account for the number of milk haul trucks in that county. It has a lower bound of zero. Bulk raw milk can also enter *Trans1* from raw milk produced in a different county, to reflect the case where milk produced in one county is processed in a different one. The arcs exiting out of *Trans1* can either go to the first level of processing, *Creamery1Start* at time period, *t*, in the same county, or be transported to a different county, *OtherRegion*, to be processed at time period, *t+1*. We use a time period of *t+1* because it does not take any longer than a day to ship bulk milk from one part of California to another. The arc between *Trans1* and *Creamery1Start* has a lower bound in order to keep a certain amount of bulk milk in the same county where it is produced.

Milk processing within the county occurs in two levels. The first level of milk processing begins at the node *Creamery1Start* at time period *t*, and ends at the node *Creamery1End* at time period *t+1* because this processing takes a single day. The arc connecting *Creamery1Start* and *Creamery1End* has an upper bound that signifies the maximum operating capacity of the level-one creameries in each county. The arc exiting *Creamery1End* at time period, *t+1*, connects to the second transportation node, *Trans2* at time period, *t+1*.

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The second transportation node, *Trans2,* has incoming arcs from *Creamery1End* at *t+1* and from bulk milk coming in from a different county at time period *t+2*. The arcs exiting *Trans2* connect to *Population* at time period, t+1, *OtherRegion* at time period, *t+2*, and the beginning of second level of milk processing, *Creamery2Start*. The node, *Population* is the end of the milk and dairy industry and represents the consumption of dairy products. The arc between *Trans2* and *Creamery2Start* has a lower bound in order to keep a certain amount of bulk milk in the same county in which it is produced.

The second level of milk processing begins at the node *Creamery2Start* at time period, *t+1*, and ends at *Creamery2End* at time period, *t+2*. The arc connecting these two nodes has an upper bound that signifies the maximum operating capacity of the level-two creameries. From *Creamery2Start* to *Creamery2End*, there is movement from one time layer to the next in order to account for the processing time at the creameries. The arc exiting *Creamery2End* connects to the third and final transportation node, *Trans3*, at time period, *t+2*.

The final transportation node *Trans3* has a second incoming arc from *OtherRegion* at time period *t+3*, and exiting arcs to *OtherRegion* at time period *t+3* and to *Population* at time period *t+2*. The arc between *Creamery2End* and *Trans3* has an upper bound to account for the trucking capacity within each county.

We replicate this basic structure for each county to obtain a simplified representation of the entire milk and dairy industry in California. We take into account the rapid movement of milk through the system by introducing a time layered effect. We also focus on the production processing and transportation of milk throughout the state. Now that we have defined our full model, our next challenge is collecting the data.
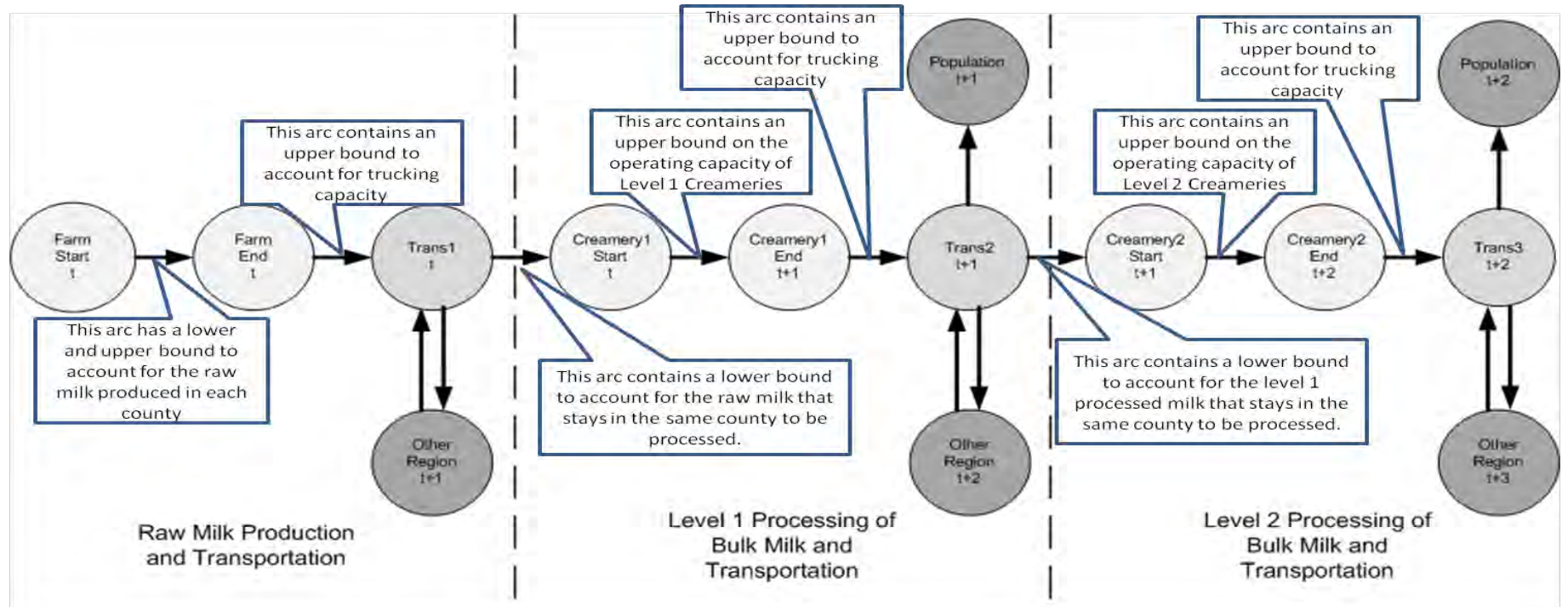
Figure 5.   Simplified representation of bulk milk movement through the processing facilities to the population. We annotate the upper and lower bounds on the arcs that control the flow of milk. We account for the different time layers in each of the nodes with t, t+1, t+2 or t+3.

C.   DATA COLLECTION

The next step in our model formulation is the collection and evaluation of data we need to build our network and the inputs needed to perform our analysis. There are six key components that we need to build our model. They are the transportation road network, the amount of milk production in each county, the amount and capacity of level one processing of bulk milk at the creameries in each county, the amount and capacity of level two processing at the creameries in each county, the operating efficiency for milk hauling trucks, and the amount of bulk milk consumed per capita in each county. Using Tulare County as an example, we next explain how we derive each of these data values. Table 1 illustrates the inputs from Tulare County for our model. Appendix A contains the full data table of all of the capacities for each of the counties.

1.   Transportation Network

We use state highway maps to determine the transportation network that we use to connect all of the counties in California as well as reaching out of (see Figure 3). Within our network, we assume that the roadways each have an infinite capacity. This means that there are no constraints placed on the amount of trucks that can move milk within each county's production and processing capabilities, between counties, or between California and milk going out of state. This is a modeling decision that we made since we are tracking the number of trucks available and not the capacity on the roads. We assume that our transportation network is the only means in which, milk can move throughout the state.

2.   Bulk Milk Production

The next piece of data that we need for our model is to know how much milk is produced in each county. We estimate the amount of bulk milk produced in each county by taking the amount of milk producing cows in each county and multiplying by the daily average amount of raw milk produced.

$$RawMilkProd = NumMilkProdCows \times DailyAvgAmtMilkProdPerCow$$

We estimate the *DailyAvgAmtMilProdPerCow* by taking the total amount of milk produced in California and dividing it by the total number of milk producing cows.

$$DailyAvgAmtMilkProdPerCow = \frac{TotalMilkProd}{TotalMilkProdCows \times 365}$$

We get the number of milk producing cows in each county from CDFA (CDFA 2010a), for Tulare County this is 493,292 cows. We get the total milk production and total number of milk producing cows from CDFA (CDFA 2010a). The daily average amount of milk produced per cow is 57 lbs of milk. This information is used to calculate the amount of milk production in each county. Based on this, we estimate that Tulare County produces an average of 28,214,938 lbs of raw milk each day.

3. Level One and Level Two Processing of Bulk Milk

The next piece of information we need is the capacity of the processing facilities in each county. CDFA documents the amount of dairy products hauled in and between each of the specified haul regions (CDFA 2010b). Figure 5 shows the established milk haul region in California. These milk haul regions are made up of multiple counties. For our research, all of the hauling information for these regions must be broken down to the county level. We create a list of counties in each haul region to help with the calculations below.

We need to determine the amount of bulk milk processed daily by the level one or level two creameries in each county.

$$BulkMilkProcessedEachCounty = \frac{BulkMilkShippedRegion \times NumCreameriesEachCounty}{TotalNumCreameriesRegion}$$

$$DailyMilkProcessedEachCounty = \frac{BulkMilkProcessedEachCounty}{30 days}$$

These equations give us the amount of bulk milk that is processed in each county. We get the number of creameries in each county from CDFA (CDFA 2010a). Our final step is to determine the upper bounds of the processing capacity in each county. We do this by first establishing a daily operating efficiency for the processing facilities. The daily operating efficiency is the rate at which the creameries process either bulk raw milk or other dairy products. A reasonable estimation of the operating efficiency is 88%. We

calculate this estimation by taking the amount of milk processed daily at Berkley Farms and dividing it by the total processing capability (Berkley Farms 1998). This means that there is 12% of excess processing capacity in each of the counties. We estimate the maximum operating capacity for the creameries to be:

$$Level1or2ProcCap = DailyMilkProcessedEachCounty \times (1 + (1 - .88)).$$

These calculations give us the maximum capacity for the creameries in a county which, translates into the upper bound on the arc connecting *Creamery1or2Start* to *Creamery1or2End* as seen in Figure 5. In our example looking at Tulare County we have a maximum operating capacity for level 1 creameries of 28,057,787 lbs of bulk milk and level 2 creameries of 278,641 lbs of bulk milk.

4.   Transportation of Milk

We also need the amount of trucking assets available in each county to transport bulk milk. According to Ruan Transportation (Ruan, 2011), the normal operating efficiency of transportation providers is 95%. Since Ruan is the largest transporter of bulk milk in California moving 80% of the bulk milk in the state.

Now we have an estimate for the operating efficiency of hauling bulk milk, we can determine the upper bound for the arc connecting *FarmEnd* to *Trans1*. Since the operating efficiency is 95% that means we have 5% additional hauling capacity. We determine the maximum hauling capacity for the movement of raw bulk milk in each county to be:

$$RawMilkHaulingCap = RawMilkProd \times (1 + (1 - .95)).$$

For Tulare County, we estimate that to be 29,625,685 lbs. We use the same formulation to determine the maximum hauling capacity of bulk milk hauled from creamery1 to creamery2. For Tulare County, these are 29,460,677 and 261,226 lbs.
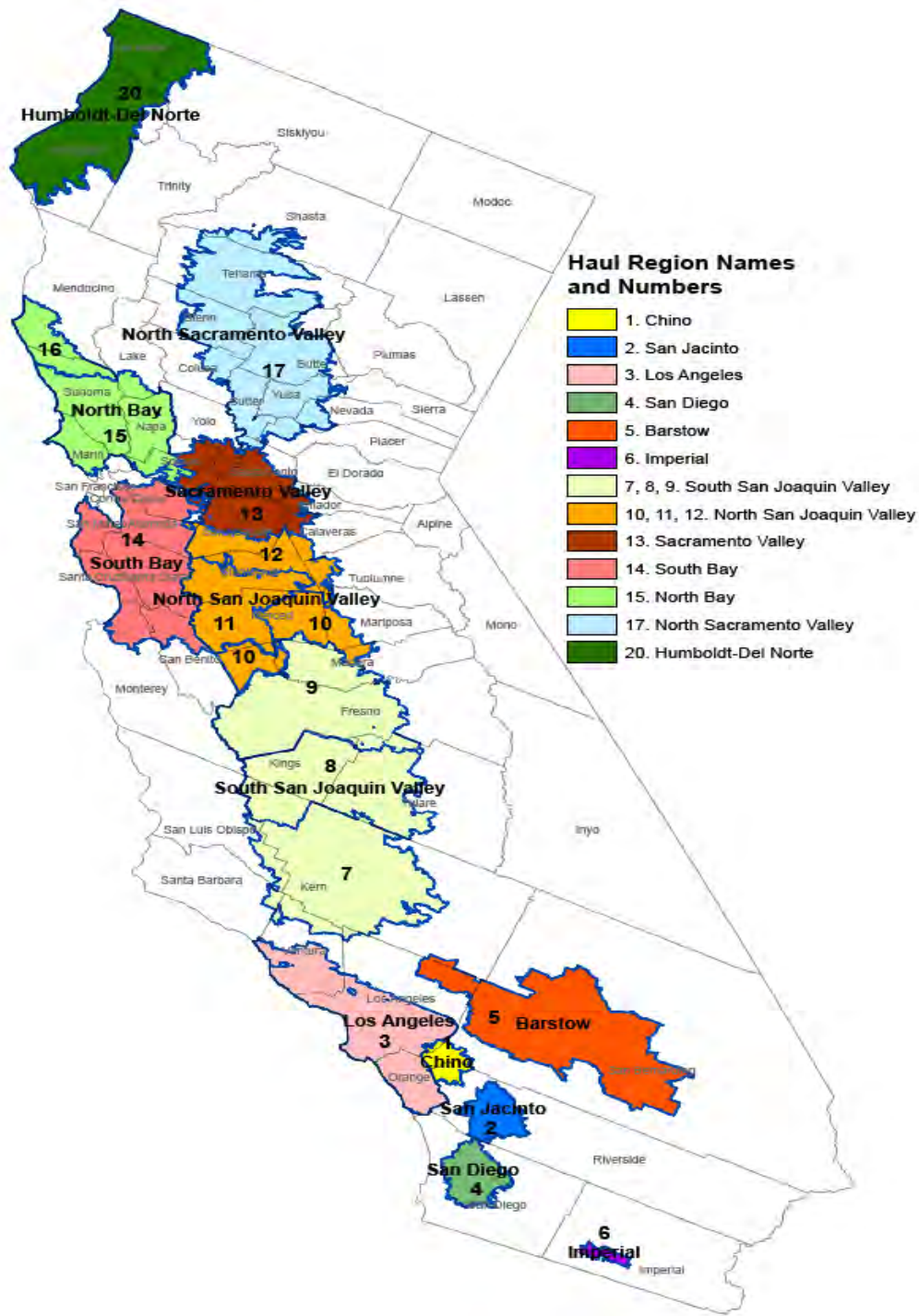
Figure 6.   Milk Haul Regions in California (From CDFA 2010d)

5. Demand for Bulk Milk

We estimate the demand for milk in each county as follows. We measure the effects of shortages among different scenarios in terms of how much demand is not being met for the population in each county. We determine the demand of level one bulk milk to be:

$$Level1Demand = \frac{CountyPop \times PercentLevel1Consumed \times TotalBulkMilkConsumed}{365}.$$

TotalBulkMilkConsumed is the total amount of dairy products consumed per person in one year. This information is from the USDA (USDA 2010). *PercentLevel1Consumed* is the percentage of total bulk milk that is used for level one processing. *CountyPop* is the population in each county in California, and the information is from the United States Census Bureau (US Census Bureau, 2010). The calculation for *Level2Demand* is:

$$Level2Demand = \frac{CountyPop \times PercentLevel2Consumed \times TotalBulkMilkConsumed}{365}.$$

We estimate the demand for milk in Tulare County to be 689,949 lbs for level-one processed milk, and 18,886 lbs for level-two processed milk.

County	Raw Milk Production and Transportation		Level 1 Processing and Transportation		Level 2 Processing and Transportation		Demand	
	RawMilk Prod	RawMilk HaulingCap	Level1 ProcCap	Level1 HaulingCap	Level2 ProcCap	Level2 HaulingCap	Level1 Demand	Level2 Demand
Tulare	28,200,000	29,600,000	28,100,000	29,500,000	279,000	261,000	690,000	18,900

Table 1.   Data table for Tulare County of the capacities on the arcs in our full model. The capacities for each of these arcs are measured in lbs.

D.   MATHEMATICAL MODEL

1.   The Operator's Problem

We develop the operator's problem to make sure that we have a basic understanding of the flow of bulk milk through our abstracted system. The goal of the

operator's problem is to move milk throughout the network while satisfying the demand of both level one and level two processed milk in each of the counties in California. Our objective is to find an optimal solution where no shortages for the population exist. The optimal solution through our network informs us whether or not current production, hauling, and processing capacities are able to fully satisfy the demand for milk in California.

Sets:

$t \in T$	Time periods in T
$n \in N$	Nodes in network (alias n,i,j,c)
$(i, j, t) \in A$	Arcs in network from node i to node j starting in time layer t

Notation:

$in(c,t)$	Arcs going into node (c,t)
$out(c,t)$	Arcs going out of node (c,t)
$start(i, j, t)$	Node at which arc (i, j, t) starts
$end(i, j, t)$	Node at which arc (i, j, t) ends

Data:

$u_{i,j,t}$	Upper limit on arc (i,j,t)
$l_{i,j,t}$	Lower limit on arc (i,j,t)
$c_{i,j,t}$	Importance on arc (i,j,t), $c_{i,j,t} \in \{0,1\}$
v	Total milk flowing through system

Special Nodes:

a	Super source node
z	Super sink node

Variables:

$Y_{i,j,t}$	Flow of pounds of milk on arc (i,j,t)
$S_{i,j,t}$	Shortage in pounds of milk on arc (i,j,t)

Formulation: [dual variables]

$$\min_{Y,S} \sum_{(i,j,t)\in A} c_{i,j,t}S_{i,j,t} \qquad\qquad\qquad \text{(D0)}$$

Subject to:

$$-\sum_{(a,i,t)\in A} Y_{a,i,t} = -v \qquad\qquad\qquad\qquad [\rho_a] \qquad\qquad \text{(D1)}$$

$$\sum_{(i,z,t)\in A} Y_{i,z,t} = v \qquad\qquad\qquad\qquad\qquad [\rho_z] \qquad\qquad \text{(D2)}$$

$$\sum_{(i,c,t)\in in(c,t)} Y_{i,c,t} - \sum_{(c,i,t)\in out(c,t)} Y_{c,i,t} = 0 \qquad \forall \text{ nodes } c \text{ on layer } t \quad [\rho_{c,t}] \qquad\qquad \text{(D3)}$$

$$Y_{i,j,t} \le u_{i,j,t} \qquad\qquad \forall (i,j,t) \in A \qquad\qquad\qquad [\pi_{i,j,t}] \qquad\qquad \text{(D4)}$$

$$0 \le Y_{i,j,t} \qquad\qquad\qquad \forall (i,j,t) \in A \qquad\qquad\qquad\qquad\qquad\qquad \text{(D5)}$$

$$-Y_{i,j,t} - S_{i,j,t} \le -l_{i,j,t} \qquad \forall (i,j,t) \in A \qquad\qquad\qquad [\mu_{i,j,t}] \qquad\qquad \text{(D6)}$$

$$0 \le S_{i,j,t} \qquad\qquad\qquad \forall (i,j,t) \in A \qquad\qquad\qquad\qquad\qquad\qquad \text{(D7)}$$

Discussion:

The objective function (D0) calculates the amount of shortages in our network during normal operations. Constraints (D1), (D2), and (D3) ensure that there is a balance of supply and demand to each of the nodes in our network. Constraint (D4) ensures that we do not exceed the capacity on any arc in our network. Constraints (D5) and (D7) makes sure that we have non-negativity for both our amount of bulk milk flowing as well as shortages seen on any given arc. Constraint (D6) determines if a shortage exists on arc (*i,j*).

2.   Attacker Defender Problem

Building on this operator's model, we present an AD model to determine where the critical nodes and arcs exist, and to do additional analysis on our scenarios in order to determine worst-case disruptions. An attack in our model is when we eliminate one of the nodes in our network in a specific time period. The nodes that we can attack are the nodes at the dairy farms, level one and level two processing facilities, and the hauling capacity in each of the counties. For example we analyze the effects of an attack on the dairy farms in Tulare County at time period two.

Additional Sets:

$(i, j, t) \in B$ Attackable arcs (i,j,t)

Additional Data:

M Maximum number of attacks allowed

$r(i, j, t)$ Reconstitution time of arc (i,j,t)

Additional Variables:

$X_{i,j,t}$ 1 if arc(i,j,t) attacked, variable exists only if
                                   $(i, j, t) \in B$

Formulation:

$$\max_{X} \min_{Y,S} \sum_{(i,j,t)\in A} c_{i,j,t} S_{i,j,t} + 4.1 \sum_{(i,j,t)\in B} \left(\sum_{t'=t-r(i,j,t)}^{t} X_{i,j,t'} \right) Y_{i,j,t} \qquad (A0)$$

s.t. (D1)-(D7) and

$$\sum_{(i,j,t')\in B} X_{i,j,t'} \leq M \qquad (A1)$$

$$X_{i,j,t'} \in \{0,1\} \qquad (A2)$$

Discussion:

Our new objective function (A0) determines the shortage of bulk milk in pounds when attacks occur within the milk and dairy industry. We account for the reconstitution for the dairy farms, processing facilities, and transportation of bulk milk by introducing a reconstitution element, $r(i, j, t)$. We penalize the flow on arc (i, j, t) if any arc (i, j, t') for $t' = t - r(i, j, t)$ and is attacked. We choose a penalty factor of 4.1 because flow on any arc can decrease the shortage by at most 4(max importance) based on the structure of our model. For example, if we attack the *FarmStart* to *FarmEnd* arc in Tulare County and if any milk goes through that arc we use our penalty factor of 4.1 because the penalized milk will also be moving through the two processing arcs, and transportation arc before reaching the population. We add the constraints (A1) to ensure that we do not exceed the maximum number of attacks that we identify. Constraints (A2) identify $X_{i,j,t'}$ as a binary variable.

3.   Solving AD Model

We solve the AD model that we created in two steps. The first step is that we take the dual of the minimization of (A0). This allows us to compute $X_{i,j,t}$ indicating where a worst case disruption occurs. The second step to determine the optimal flow of bulk milk through our network is to solve the minimization of (A0) with $X_{i,j,t}$ fixed. The dual for (A0) is:

Dual Variables (taken from duals of (D1)-(D4) and (D6)):

ρ_a

ρ_z

$\rho_{c,t}$

$\pi_{i,j,t}$

$\mu_{i,j,t}$

Formulation:

$$\max_{X,\pi,\mu} \sum_{t'=t-r(i,j,t)}^{t} X_{i,j,t'} + \sum_{i,j,t} \mu_{i,j,t}\pi_{i,j,t} - \sum_{i,j,t} l_{i,j,t}\mu_{i,j,t} \qquad \text{(DU0)}$$

Subject to:

$$\rho_a - \rho_z = 0 \qquad\qquad [v] \qquad\qquad \text{(DU1)}$$

$$-\mu_{i,j,t} \le c_{i,j,t} \qquad\qquad [s_{i,j,t}] \qquad\qquad \text{(DU2)}$$

$$-\rho_{start(i,j,t)} + \rho_{end(i,j,t)} + \pi_{i,j,t} - \mu_{i,j,t} \le 4.1\left(\sum_{t'=t-r(i,j,t)}^{t} X_{i,j,t'}\right) \qquad [Y_{i,j,t}] \qquad \text{(DU3)}$$

$$\mu_{i,j,t} \le 0 \qquad\qquad\qquad\qquad \text{(DU4)}$$

$$\pi_{i,j,t} \le 0 \qquad\qquad\qquad\qquad \text{(DU5)}$$

$$\rho_{c,t}, \rho_a, \rho_z \qquad\qquad [\text{unrestricted}] \quad \text{(DU6)}$$

Discussion:

We now have the tools developed to begin our analysis on the milk and dairy industry in California. In the next chapter we explore the impact of a FMD outbreak that completely quarantines each of the counties, a worst case disruption with up to 15 attacks

within a 45 day window, and finally an isolation based scenario where we cut off northern from southern California and see what the results are to the milk and dairy industry.

IV. RESULTS

We utilize our model with the data we collected to analyze the impact of three different scenarios on the milk and dairy industry. In these scenarios, we analyze (1) the effects of a FMD outbreak in each of the counties in California, (2) the worst case disruptions over a 45 day window with up to 15 different attacks, and (3) the shortages and flow of milk when there is a division separating Northern from Southern California due to large scale flooding. For each of these scenarios, we use the General Algebraic Modeling System (GAMS) (GAMS, 2010) and is solved utilizing CPLEX 12.02 (ILOG, 2007) on a personal computer with an Intel Core Duo CPU at 3.66 GHz.

A. IMPACT FROM A FOOT AND MOUTH DISEASE OUTBREAK

1. Scenario: Processed Milk Not Being Able to Reach Population

The first scenario that we analyze is a FMD outbreak within a single county in California; we measure the resulting shortages of milk to the population in the state. We model a FMD outbreak by completely eliminating the production, processing and hauling capacities within the selected county. This simulates a quarantine of the milk process flow within the infected county. We also do not allow milk that has been processed from another county to enter the county that is quarantined. This type of scenario can be used for any situation that stops the production, processing, and movement of milk in a county. For this scenario, we use a seven day time layering to simulate the impact of a week-long quarantine of an infected county. We repeat this analysis for each county in California.

The model for this scenario is made up of 8521 nodes and 12565 arcs. The computation time to solve is approximately 52 seconds for each county.

Table 2 summarizes the shortages associated with a seven-day stoppage for each California County. One of the most interesting findings is that Los Angeles County ranks number one. We estimate that a seven-day stoppage to the production, processing, and movement of milk in Los Angeles will cause a shortage of milk throughout California of 114,000,000 lbs. The reasoning for such a large shortage is because of the large population and processing facilities in Los Angeles.

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This information helps us determine which counties are the most critical to the continuity of the milk and dairy industry. This enables us to plan for varying scenarios one of which, could be a FMD outbreak. Under a FMD outbreak we know which counties are critical, and this helps us determine what type of strategy to adopt when an outbreak occurs. Knowing the impact of county quarantines allow us to evaluate the relative merits of different strategies, for example, whether to slaughter infected cattle or vaccinate herds in order to minimize the quarantine time.

Rank	County	Shortage (lbs of Milk)	Rank	County	Shortage (lbs of Milk)
1	LosAngeles	114,000,000	30	Shasta	2,091,346
2	SanDiego	37,192,527	31	Imperial	1,927,075
3	Orange	34,953,574	32	Nevada	1,901,126
4	Tulare	30,439,135	33	Amador	1,831,699
5	Riverside	29,224,142	34	Kings	1,717,939
6	SanBernadino	23,300,254	35	Madera	1,716,415
7	SantaClara	20,609,193	36	Napa	1,554,949
8	Sacramento	20,070,694	37	Humboldt	1,505,855
9	Alameda	17,223,757	38	Calaveras	1,394,304
10	ContraCosta	12,024,718	39	Sutter	1,069,514
11	Fresno	10,569,579	40	Mendocino	993,597
12	Kern	9,672,985	41	Tuolumne	842,629
13	SanFrancisco	9,415,821	42	Sierra	772,290
14	Ventura	9,272,914	43	Lake	753,847
15	SanMateo	8,302,944	44	Plumas	735,636
16	SanJoaquin	7,793,339	45	Tehama	706,027
17	Placer	5,926,233	46	SanBenito	635,814
18	Stanislaus	5,893,968	47	Siskiyou	515,437
19	Sonoma	5,451,873	48	Lassen	503,265
20	Monterey	4,738,987	49	Inyo	348,983
21	Solano	4,702,772	50	DelNorte	336,211
22	SantaBarbara	4,700,728	51	Glenn	326,799
23	ElDorado	3,892,420	52	Colusa	246,217
24	SanLuisObispo	3,083,003	53	Mariposa	205,464
25	SantaCruz	2,958,827	54	Trinity	163,579
26	Marin	2,895,682	55	Mono	149,282
27	Merced	2,832,987	56	Modoc	105,168
28	Butte	2,547,241	57	Alpine	12,022
29	Yuba	2,448,347	58	Yolo	0

Table 2. Ranking of counties by shortages of bulk milk in California caused by a FMD outbreak. The amount of shortage is in pounds of bulk milk quarantine is over a seven day time period.

2. Scenario: Processed Milk Able to Reach Population

We continue our analysis of this scenario by adjusting our parameters to allow fully processed milk to move into a county where a quarantine occurs. This enables

demand to be satisfied from a county that is not affected by the quarantine. With these updated parameters, the size of our model and the computation time to solve do not change.

Rank	County	Shortage (lbs of Milk)
1	Tulare	33,150,000
2	Riverside	5,420,000
3	Yuba	2,450,000
4	SanDiego	1,930,000
5	Placer	1,900,000
6	ElDorado	1,830,000
7	Amador	1,390,000
8	Calaveras	850,000
9	Nevada	770,000
10	Sierra	740,000
11	Plumas	500,000
12	Kern	350,000
13	Tuolumne	210,000
14	Inyo	150,000
15	Lassen	100,000
16	Humboldt	9,000

Table 3. Ranking of counties by shortages of bulk milk in California caused by a FMD outbreak when process milk can move to consumers in a quarantined county. The amount of shortage is in pounds of bulk milk and the quarantine is over a seven day time period.

In this updated scenario, we estimate that there are only sixteen counties that will cause shortages of milk in California if a FMD scenario occurs. Table 3 ranks these counties and the results are interesting. A quarantine in Tulare County over seven days has the greatest impact to shortages felt within all of California. This is caused by the fact that Tulare County is the top milk producing and processing county in California. Quarantines in Riverside and San Diego impact shortages because they interrupt the flow of milk in Southern California where there is not enough capacity to fulfill consumer demand. These results are also affected by the isolation of certain parts of California due

to the fact that no milk is able to move any further on the transportation network. This is the case in Placer and Yuba Counties.

B.   RESILIENCY OF THE MILK AND DAIRY INDUSTRY IN CALIFORNIA WHEN FACING WORST CASE SCENARIOS

The next part of our analysis seeks to identify the most critical nodes in California's milk and dairy network. In this scenario, we consider combinations of 1 through 15 attacks, each which may be targeted on any farm, processing facility, or hauling capacity in any county in California, with a time layering of 45 days. As part of this scenario, we include reconstitution times of farms to be one week, processing facilities to be one month (30 days), and hauling capacity to be one day. The reconstitution time is the amount of time needed to return to normal operation following an attack. We choose one week for a dairy farm because we think that moving dairy cows from one area to another would take approximately one week. We choose 30 days for the processing facilities because we assume that due to the size of the plants and the specialized equipment that they use it would take longer for them to get operational after an attack. Finally we choose one day for the reconstitution time for the hauling capacity because the transportation companies can reroute their milk hauling trucks easily. A one day reconstitution time seems reasonable.

The model for this scenario is made up of 54,767 nodes and 80,775 arcs. The computation time to solve for all 1 through 15 attacks is approximately 13 hours and 15 minutes.

Figure 7 illustrates the impact of varying attacks from 1 to 15 on the state of California. We can see from the graph that California does not begin to feel the impact from attacks until five attacks are reached. The total production of bulk milk in a 45 day time period is 4,451,000,000 lbs and the demand for bulk milk over this same time period in California is 2,745,000,000 lbs. The first four attacks significantly reduce the amount of milk that may be shipped out of state from California, but does not create significant in-state shortages. With 15 attacks, the total shortage of bulk milk is 2,783,000,000 lbs. This translates into a shortage of bulk milk to California residents of 1,075,000,000 lbs.

The amount of overall shortage is 63% of the total milk produced, and California has a 39% shortage of in-state demand for bulk milk.

Upon further examination we can see that the attacks are centered around the major milk producing counties in California. Figure 8 visually identifies the counties where arracks occur for one, five, ten, and fifteen attacks. With only one attack, the attack occurs in Tulare County against the dairy farms and causes a shortage of 200,000,000 lbs of bulk milk.

When we look at five attacks, they occur in Tulare County at the dairy farms, Kern County at creamery1, Merced County at the dairy farm, Kings County at the hauling capacity node for level two milk, and Fresno County at creamery1. The overall shortage with five attacks is 1,800,000,000 lbs and the shortage specifically felt in California is 92,000,000 lbs.

At 10 attacks the counties that get attacked are Butte County at the hauling capacity node for level two milk, Fresno County at creamery1, Glenn County at the dairy farms, Kern County at creamery1, Kings County at the hauling capacity node for level two milk, Madera County at the dairy farm, Merced County at the dairy farm, Riverside County at the dairy farm, Sonoma County at the hauling capacity node for level two milk, and Tulare County at the dairy farm. The overall shortage with ten counties is 2,772,000,000 lbs and the shortage felts in California is 992,000,000 lbs.

The final scenario that we examine is what happens to the milk supply when 15 attacks are present. The counties that get attacked are Butte County at the hauling capacity node for level two milk, Del Norte County at the dairy farm, Fresno County at creamery1, Glenn County at the dairy farm, Humboldt County at creamery1, Kern County at creamery1, Kings County at the hauling capacity node for level two milk, Madera County at the dairy farm, Merced County at the dairy farm, Riverside County at the dairy farm, Sacramento County at the dairy farm, Sonoma County at the hauling capacity node for level two milk, Tehama County at the farm, and Tulare County at the dairy farm. The overall shortage with 15 counties is 2,783,000,000 lbs and the shortage felts in California is 1,075,000,000 lbs.
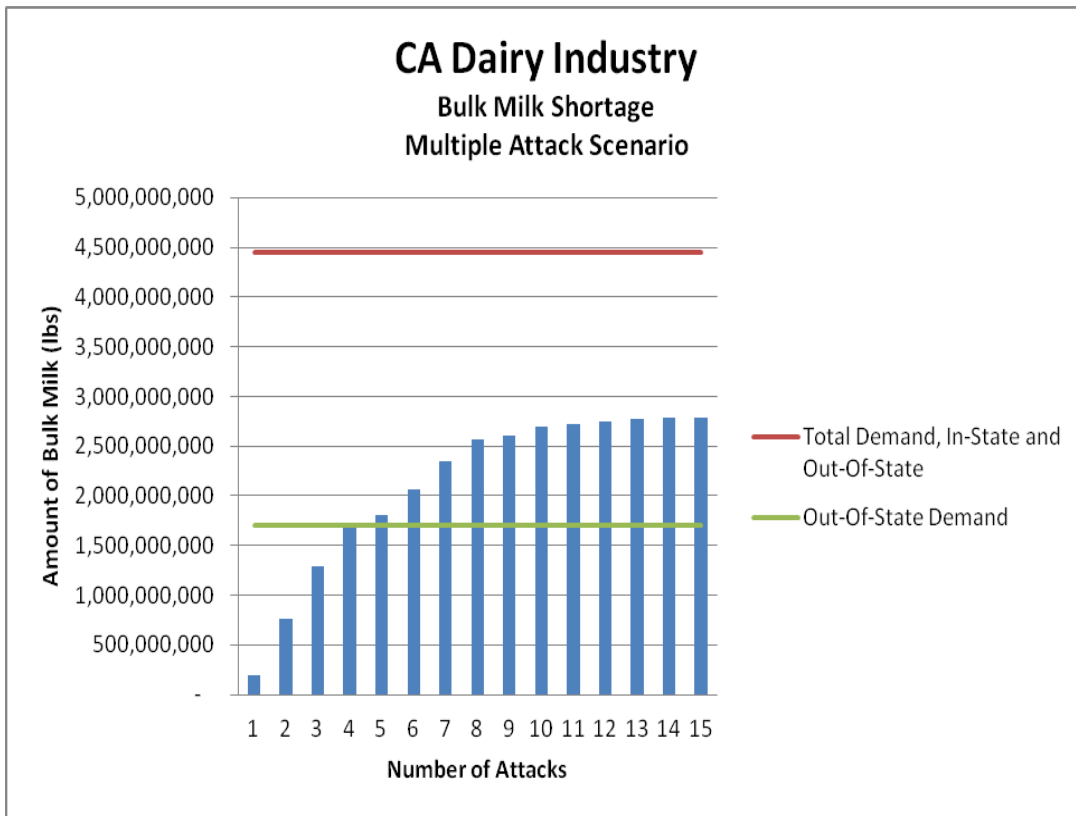
Figure 7. Graph of the results from 15 attacks over a 45 day time period. This graph
show the shortages in bulk milk felt throughout California

The results from 1 to 15 attacks on the milk and dairy industry are interesting because they highlight the areas where an intelligent adversary will concentrate their attacks. These results also give us an initial indication on the resilience of the milk and dairy industry. It takes four attacks before shortages are felt by the residents in California, assuming that California will export less milk out of state in these instances.

California Counties Attacked with 1, 5, 10, and 15 Attacks

1 Attack
Shortage 200,000,000

County	Entity Attacked	Time Period
Tulare	Farm	0

5 Attacks
Shortage 1,800,000,000

County	Entity Attacked	Time Period
Fresno	Creamery1	4
Kern	Creamery1	0
Kings	Level 2 Hauling	1
Merced	Farm	0
Tulare	Farm	0

10 Attacks
Shortage 2,700,000,000

County	Entity Attacked	Time Period
Butte	Level 2 Hauling	0
Fresno	Creamery1	0
Glenn	Farm	0
Kern	Creamery1	0
Kings	Level 2 Hauling	0
Madera	Farm	0
Merced	Farm	0
Riverside	Farm	0
Sonoma	Level 2 Hauling	0
Tulare	Farm	0

15 Attacks
Shortage 2,783,000,000

County	Entity Attacked	Time Period
Butte	Level 2 Hauling	0
DelNorte	Farm	0
Fresno	Creamery1	0
Glenn	Farm	0
Humboldt	Creamery1	0
Kern	Creamery1	0
Kings	Level 2 Hauling	0
Madera	Farm	0
Marin	Level 1 Hauling	0
Merced	Farm	0
Riverside	Farm	0
Sacramento	Farm	0
Sonoma	Level 2 Hauling	0
Tehama	Farm	0
Tulare	Farm	0

Figure 8. Illustration of which counties are attacked in our AD model of the milk and dairy industry. The counties that are attacked are highlighted in yellow. The figure for 1 and 5 attacks highlight the counties to which the California Milk and dairy industry is most sensitive. Multiple attack strategies exist that cause the same worst-case shortage. The pictures above show one specific attack strategy for the scenarios depicted.

C.   IMPACT FROM SPLITTING NORTHERN AND SOUTHERN CALIFORNIA

The final scenario that we examine is a break in the arcs connecting the distribution of milk between Northern and Southern California. This scenario simulates the impact of a natural disaster to the transportation network of the milk and dairy industry between Northern and Southern California. An example of such a natural disaster is a large scale flood. We run this scenario over a 7 day time period and measure the impact. Finally, we test two different cuts between the North and the South. The first is a cut between Monterey and San Luis Obispo, Madera and Fresno, and finally Merced and Fresno Counties which, we call "cut A". The second test we did was to cut San Luis

Obispo and Santa Barbara, Kings and Kern, and Tulare and Kerns Counties which, we call "cut B".

For each cut the model is made up of 8521 nodes and 12565 arcs. The computation time to solve for each county is approximately 52 seconds.
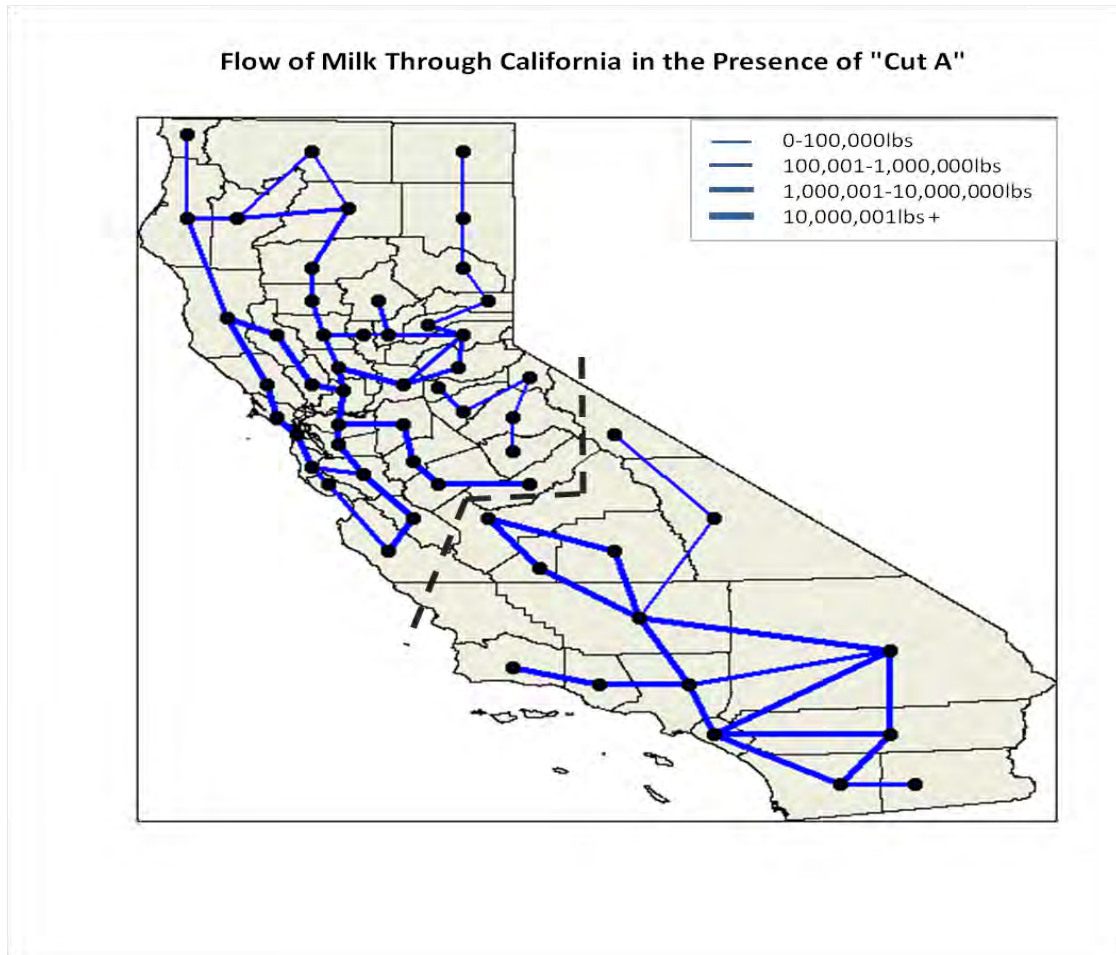
Figure 9.   Flow of milk in California when there is a cut between Monterey and San Luis Obispo, Madera and Fresno, and finally Merced and Fresno Counties. The arcs connecting the milk and dairy industry between counties have varying thicknesses to account for differing amounts of milk flowing between them.

In the presence of "cut A", all of the demand for bulk milk in each the counties is filled and there are no shortages. You can see the flow of milk in this scenario in Figure 9. This means that all of the counties are able to produce enough milk and utilize their capacity for processing and distributing milk to satisfy all of the demand.

With "cut B", we do have shortages in the southern counties in California. The total shortage in California is 209,264,000lbs of bulk milk. You can see the flow of milk in this scenario in Figure 10. The amount of shortage in each county is highlighted in Table 2. When we do this cut there is not enough production to meet the demands in Southern California. The counties in Northern California are able to get all of their demand filled.

Figure 10.   Flow of milk in California when there is a cut between San Luis Obispo and Santa Barbara, Kings and Kern, and Tulare and Kerns Counties. The chart at the right shows the comparison between the shortages of milk in each county compared to the total demand of milk over seven days.

The shortage of milk by caused by cut B is very interesting and gives us insight into where the critical arcs exist in California. When we compare cut A to cut B we see that it is more important to keep the major milk producing counties such as Tulare County connected to the Southern Counties than to the Northern Counties, in the split. Shortages arise because demand is not able to be met in heavily populated counties, namely Los Angeles, Orange, and San Diego. This information can help planners decide

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where to invest in the milk and dairy industry to ensure that enough milk is flowing to the through the milk and dairy network, or develop plans to minimize the impact of shortages in these counties.

County	Shortage
Imperial	1100000
Inyo	89000
Kern	5360000
LosAngeles	107150000
Mono	85000
Orange	29240000
Riverside	10890000
SanBernadino	19880000
SanDiego	27330000
SantaBarbara	1340000
Ventura	6800000

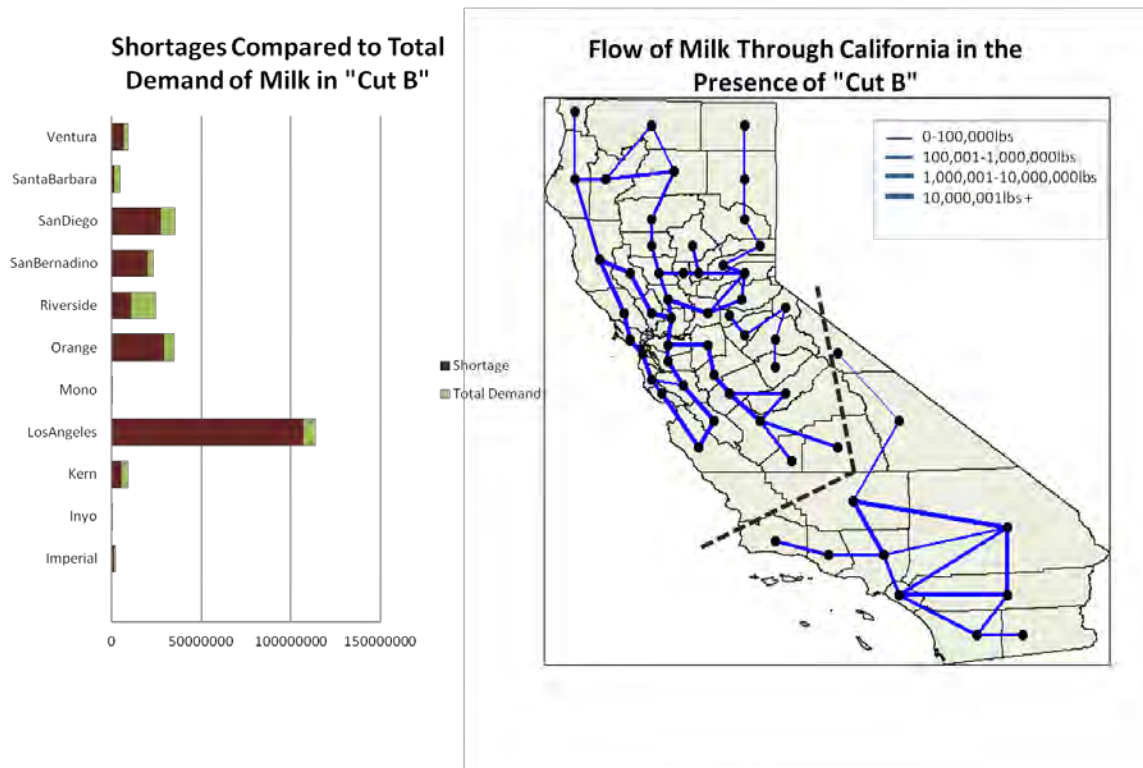Table 4.   Bulk milk shortage in Southern California Counties when there is a cut between San Luis Obispo and Santa Barbara, Kings and Kern, and Tulare and Kerns Counties.

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V.   CONCLUSION

Milk moves through the milk and dairy industry in California extremely rapidly and understanding the impact caused by deliberate or non-deliberate interruptions is important to estimating where vulnerabilities may exist in this industry. Two of the key reasons for studying the milk and dairy industry are the economic impact that disruptions may cause, and the number of people affected by shortages of milk. We focus our analysis on the production, processing, and distribution of bulk milk in California. Our analysis gives us key insights into the movement of bulk milk and how disruptions affect the California consumers.

The results from the scenarios we ran show us what factors to look at when faced with decisions that could negatively impact the production, processing, and distribution of milk. Depending on the scenario and the severity of a quarantine we realize that it is more important to examine the size of the population in the county and the processing capacity than the production capacity. We learn that it is important to ensure that there is enough production and processing capacity in the southern counties in California to satisfy the demands of the large populated areas (e.g., Los Angeles, San Diego, and Orange Counties). We also found that we can have up to four disruptions in a 45 day window before shortages in the supply of milk will necessarily impact the residents in California. We do assume that any shortages that are realized will first impact the milk that is being exported to another state.

The analysis and results in this thesis have the potential to be helpful to CDFA and CalEMA. Specifically, our analysis of the milk and dairy industry can illuminate where vulnerabilities may exist. This can help CDFA and CalEMA in justifying additional funding to mitigate the impact from vulnerabilities that can be exploited by an intelligent attacker. It can also help them develop Continuity of Operations plans for specific scenarios such as a FMD outbreak.

This research is just the beginning when it comes to analysis on the milk and dairy industry that can be accomplished to help decision makers at the state and national

levels. Our results are derived from notional data that we found primarily through open source information. In the future, if more detailed information on the milk and dairy is available, then results from future analysis can be even better defined. The model we built and used can be refined even further and polished to eventually become a tool to be used to analyze the milk and dairy industry by CDFA and CalEMA. The techniques that we used in determining the size and scope of the milk and dairy network can be updated easily so other agricultural commodities can be analyzed for their vulnerabilities.

APPENDIX   DATA TABLE LISTING THE CAPACITIES FOR ALL OF THE MILK AND DAIRY INDUSTRY COMPONENTS IN EACH COUNTY IN CALIFORNIA

County	Raw Milk Production and Transportation		Level 1 Processing and Transportation		Level 2 Processing and Transportation		Demand	
	RawMilk Prod	RawMilk HaulingCap	Level1 ProcCap	Level1 HaulingCap	Level2 ProcCap	Level2 HaulingCap	Level1 Demand	Level2 Demand
Alameda	0	0	0	0	0	0	2,390,000	65,600
Alpine	0	0	0	0	0	0	1,670	46
Amador	0	0	0	0	0	0	60,800	1,660
Butte	14,100	14,800	46,300	48,600	0	0	354,000	9,700
Calaveras	0	0	0	0	0	0	75,000	2,050
Colusa	0	0	0	0	0	0	34,200	937
ContraCosta	0	0	0	0	0	0	1,670,000	45,800
DelNorte	234,000	246,000	71,400	74,900	0	0	46,800	1,280
ElDorado	0	0	0	0	0	0	287,000	7,840
Fresno	6,620,000	6,950,000	8,970,000	9,420,000	89,100	83,500	1,470,000	40,200
Glenn	1,000,000	1,050,000	648,000	680,000	0	0	45,400	1,240
Humboldt	891,000	936,000	547,000	575,000	0	0	208,000	5,700
Imperial	429,000	450,000	0	0	0	0	268,000	7,330
Inyo	0	0	0	0	0	0	27,800	760
Kern	9,570,000	10,000,000	4,660,000	4,890,000	46,300	43,400	1,300,000	35,500
Kings	10,400,000	10,900,000	13,200,000	13,900,000	131,000	123,000	239,000	6,540
Lake	0	0	0	0	0	0	105,000	2,870
Lassen	0	0	0	0	0	0	55,400	1,520
LosAngeles	0	0	17,900,000	18,800,000	922,000	864,000	15,800,000	433,000
Madera	4,220,000	4,430,000	4,840,000	5,080,000	48,000	45,000	239,000	6,530
Marin	531,000	558,000	473,000	496,000	5,840	5,470	403,000	11,000
Mariposa	0	0	0	0	0	0	28,600	782
Mendocino	0	0	41,100	43,100	508	476	138,000	3,780
Merced	15,000,000	15,700,000	13,900,000	14,600,000	148,000	139,000	394,000	10,800
Modoc	0	0	0	0	0	0	14,600	400
Mono	0	0	0	0	0	0	20,800	568
Monterey	0	0	1,650,000	1,730,000	61,200	57,400	659,000	18,000
Napa	0	0	0	0	0	0	216,000	5,920
Nevada	0	0	0	0	0	0	157,000	4,300
Orange	0	0	0	0	0	0	4,860,000	133,000
Placer	0	0	0	0	0	0	560,000	15,300

County	Raw Milk Production and Transportation		Level 1 Processing and Transportation		Level 2 Processing and Transportation		Demand	
	RawMilk Prod	RawMilk HaulingCap	Level1 ProcCap	Level1 HaulingCap	Level2 ProcCap	Level2 HaulingCap	Level1 Demand	Level2 Demand
Plumas	0	0	0	0	0	0	32,300	884
Riverside	2,740,000	2,870,000	2,210,000	2,320,000	1,100,000	1,030,000	3,410,000	93,400
Sacramento	885,000	929,000	456,000	479,000	0	0	2,250,000	61,600
SanBenito	0	0	2,470,000	2,590,000	91,800	86,100	88,400	2,420
SanBernadino	0	0	32,600	34,200	0	0	3,240,000	88,700
SanDiego	147,000	154,000	0	0	0	0	4,900,000	134,000
SanFrancisco	0	0	0	0	0	0	1,310,000	35,800
SanJoaquin	5,800,000	6,090,000	0	0	0	0	1,080,000	29,700
SanLuisObispo	0	0	88,000	92,400	873	819	429,000	11,700
SanMateo	0	0	0	0	0	0	1,150,000	31,600
SantaBarbara	0	0	176,000	185,000	1,750	1,640	654,000	17,900
SantaClara	0	0	0	0	0	0	2,870,000	78,400
SantaCruz	0	0	0	0	0	0	411,000	11,300
Shasta	0	0	15,400	16,200	0	0	291,000	7,960
Sierra	0	0	0	0	0	0	5,100	140
Siskiyou	36,400	38,200	23,800	25,000	0	0	71,700	1,960
Solano	0	0	26,800	28,100	0	0	654,000	17,900
Sonoma	1,520,000	1,590,000	1,420,000	1,490,000	17,500	16,400	758,000	20,800
Stanislaus	10,300,000	10,800,000	13,500,000	14,100,000	143,000	134,000	820,000	22,400
Sutter	0	0	15,400	16,200	0	0	149,000	4,070
Tehama	275,000	288,000	231,000	243,000	0	0	98,200	2,690
Trinity	0	0	0	0	0	0	22,700	623
Tulare	28,200,000	29,600,000	28,100,000	29,500,000	279,000	261,000	690,000	18,900
Tuolumne	0	0	0	0	0	0	88,600	2,430
Ventura	0	0	0	0	0	0	1,290,000	35,300
Yolo	0	0	26,800	28,100	0	0	320,000	8,760
Yuba	178,000	187,000	61,700	64,800	0	0	117,000	3,210

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